(2)

NCS TIB 89-11

NATIONAL COMMUNICATIONS SYSTEM

TECHNICAL INFORMATION BULLETIN
89-11

4 ESS™ SWITCH
ELECTROMAGNETIC PULSE
ASSESSMENT

VOLUME 2: TASK 3
LABORATORY TESTING
OF THE 4 ESS SWITCH

SCIENTIFIC AND TECHNICAL
FINAL REPORT

AT&T TECHNOLOGIES
FEDERAL SYSTEMS
CONTRACT: DCA100-88-C-0027

DECEMBER 1, 1989

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
December 1, 1989

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
4ESS Switch Electromagnetic Pulse Assessment, Volume 2;
Task 3 Laboratory Testing of the 4 ESS Switch

5. FUNDING NUMBERS
C-DCA100-88-C-0027

6. AUTHOR(S)

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
AT&T Technologies
Federal Systems
1120 20th Street, N.W.
Washington, DC

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Communications System
Office of Technology & Standards
Washington, DC 20305-2010

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NCS TIB 89-11

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for Public Release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The 4ESS Switch was subjected to test sequences representative of electromagnetic stresses following a high-altitude nuclear blast. These laboratory tests revealed some potential equipment sensitivities requiring only minor modifications. With these modifications implemented, the 4 ESS Switch demonstrated considerable robustness in servicing calls following current injection stress. (JHD)

14. SUBJECT TERMS
4 ESS Switch
EMP

15. NUMBER OF PAGES
33

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

SUMMARY

The content of this report is defined by paragraph 3.3 of the Statement of Work for Contract DCA100-88-C-0027. This report documents Task 3, Laboratory Testing of the 4 ESS™ Switch.

In this task, the 4 ESS Switch was subjected to test sequences representative of electromagnetic stresses following a high-altitude nuclear blast. These laboratory tests revealed some potential equipment sensitivities requiring only minor modifications. With these modifications implemented, the 4 ESS Switch demonstrated considerable robustness in servicing calls following current injection stress.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. PROGRAM INTRODUCTION

In response to Presidential Directive/NSC-53, "National Security Telecommunications Policy," and its reaffirmation in 1983 as National Security Decision Directive 97, the National Communications System (NCS) has undertaken a series of contracts to assess the performance of various Public Switched Network (PSN) telecommunications systems to the effects of nuclear weapons. AT&T has performed nuclear weapons effects assessments of its T1 Carrier System, the FT3C Fiber Optic Transmission System, the D4 Channel Bank, and the 5ESS® Switching System under funding from NCS. The 4 ESS Switch is the dominant switching vehicle in the AT&T Switched Network (ASN). As such, its performance in nuclear weapons environments is crucial to certain NCS national level programs and has been identified as a key to the success of the NCS Electromagnetic Pulse (EMP) mitigation program.

A program has been outlined to determine the effects of EMP on the 4 ESS Switch. The results of this program may be used by NCS to model the performance of the ASN in nuclear weapons environments. The test program designed for the 4 ESS Switch EMP Assessment is divided into four tasks:

a. Design and installation of the experimental test bed - Included the switching system to be tested, the portable enclosures, the EMP test data acquisition system, and the traffic, signaling, and maintenance interfaces to the system under test.

b. Determination of the system performance baseline - Characterized the test-bed performance specifications in an unstressed condition. This data will form the basis of comparison for information gathered during the EMP testing.

c. A laboratory test phase performed at the installation site in Colorado Springs, Colorado - Identified potential vulnerabilities in both hardware and logical operation. The method of testing during this phase involved isolated electrical stimulation of switch elements through techniques such as current injection. The information obtained in this controlled environment provided the opportunity for developing solutions to problems that might be encountered under the Air Force Weapons Laboratory (AFWL)/Los Alamos Scientific Laboratory EMP Calibration and Simulation (ALECS) simulator in an atmosphere conducive to prompt and economical resolution.

d. Threat-level field testing of the 4 ESS Switch - Will be conducted at the ALECS threat-level field simulator.

This report covers the third task: Laboratory testing of the 4 ESS Switch at Colorado Springs.

1.1 MOTIVATION FOR LABORATORY TESTING

The laboratory test phase of the 4 ESS Switch EMP Assessment was designed to provide a training platform in preparation for the field test phase at the ALECS facility. There were several goals of this phase:

a. To allow the test team to become familiar with the test vehicle

b. To engineer and integrate a network simulation system

c. To perform several different types of system testing designed to provide insight into performance at the ALECS facility, such as:

   1. Interbay and backplane current-injection tests

   2. Bay-level electromagnetic field tests

   3. System-level electromagnetic field tests

d. To diagnose and determine remedies for disruptions initiated by laboratory testing.

1.2 LABORATORY TESTING VERSUS FIELD TESTING

The results of a laboratory test phase for an EMP assessment program are not primarily of predictive value. Ideally, the results of laboratory assessment form a superset of those responses a system will exhibit at a field test facility. If one can determine methods for comprehensive exposure of system elements to EMP-like stimuli and can determine methods for dealing with the resulting disruption then, in theory, few surprises should occur at a field test facility. Of course, there are significant differences between laboratory testing and field testing that limit this relationship.

The primary difference between laboratory tests and field tests involves the simultaneity of the stimuli. When the entire system is exposed simultaneously, a large number of interrupts can be generated throughout the switch. Individually, the switch may be able to clear the interruptions and proceed with its function, but there are nonlinear effects that arise from considerations such as finite lengths of trouble queues. Although attempts have been made during the laboratory test phase to test system-wide response, there remains a significant region of test "space" that requires exploration in a threat-level field test facility. Thus, although remedial measures have been designed or proposed for all the disruptions encountered during this task, there remains a potential for surprises (more sensitivities or fewer sensitivities) at the ALECS facility. Nevertheless, it is possible to replicate most of the effects of high-level system-wide stress through laboratory testing, albeit piecemeal. This replication is done by dividing the stresses on the switch in a manner consistent with the morphology of the switch;

namely, small wires and intrabay cabling couple best to the high-frequency components of the incident EMP field, and relatively small currents are generated in the process. Conversely, large current surges can be induced on the long interbay cables, principally the major buses, and the resulting current waveforms are relatively low in frequency.

Circuit damage rarely results from direct EMP illumination of printed circuit boards and wired backplanes. The scale dimension of the circuits does not collect enough energy relative to the dielectric strength of the components. The corresponding impairment in switch function results from systemic logic upset rather than physical damage. Once electromagnetically induced circuit noise exceeds logic levels, increased signal strength does not produce further functional impairment. Consequently, the simultaneous effect of EMP due to circuit-level coupling can be mimicked with a source that generates relatively low field levels, particularly if the signal is concentrated in the higher frequencies.

Component damage is more likely to occur on interfaces to large buses, which serve as collecting antennae over a larger area and concentrate the coupled energy. There are only a few major bus systems in the switch, so direct current injection into a single bus can still stress an appreciable fraction of the affected circuits. Moreover, sequential injection of all the major buses singly will still resolve the issue of hardware-damage susceptibility (the major concern with large current transients), and distinct circuits on separate buses are not stressed harder in tandem than individually.

The design of the current-injection methodology mirrored the considerations stated above. In order to probe the functional effects of system wide logic upset, a device was designed to couple moderate-level high-frequency signals over a large area of the switch. In order to test for hardware vulnerability to large current surges on inter bay cabling, a technique was developed to couple large currents into a small number of bus cables. Finally, to aid in troubleshooting and problem isolation, several methods were employed to couple current to individual leads and to illuminate small sections of backplane wiring.

1.3 SUMMARY RESULTS

The switch was sensitive to field levels as low as ~ 500 V/m, and induced currents as small as ~ 1 ampere. Most of the equipment bays of the switch also demonstrated sensitivity to pulses, including the Time-Multiplexed Switch (TMS), the Digital Interface Frame (DIF), the Timeslot Interchange (TSI), the Signal Processor (SP), the oscillators, the Master Control Console (MCC), the Input/Output Processor (IOP), the Central Controls (CCs), and the Common Channel Signaling System 7 (CCS 7) node. Exposure to test pulses shut down several power converters, effectively disabling the switch. Modifications were incorporated allowing power to be maintained to most of the switch as well as reducing the sensitivity of the oscillators and the MCC to the induced stresses.

With power maintained, the 1A Processor in most cases was effectively able to reconstitute the switch in a matter of minutes with no outside intervention. However, manual intervention was sometimes necessary to direct the recovery actions or power cycle equipment which was forced into a nonfunctional state. Manual action was also needed when multiple pulses occurred, in which case the 1A Processor neither processed calls nor attempted to recover itself. If serious recovery actions were required, call processing was sometimes interrupted but was usually resumed in a matter of approximately 2 to 10 minutes. Duplex failure for some of the single pieces of equipment (e.g., the DIF or the TSI) required manual intervention. Overall, the general behavior of the switch was not dissimilar to the 5ESS Switch.

2. EQUIPMENT AND INSTRUMENTATION

This section provides a brief review of the switch test-bed and describes the test and data-acquisition equipment.

2.1 SWITCH DESCRIPTION

2.1.1 Functional

A 4 ESS Switch can be thought of as a digital computer which has the capability to intermingle data streams and switch the data streams among ports. The core of this device is the 1A Processor. The CC may be thought of as its Central Processing Unit, the Call Store as its Random Access Memory, and the Program Store as its Read Only Memory, where the "operating system" and information about trunk group timeslot assignments, etc., are contained. Because of the enormous memory demands on the processor, a separate Attached Processor (AP), the 3B20 computer, is added as a more permanent memory management module. The AP also happens to be the host processor for the Control Network Interface (CNI) ring.

The processor accomplishes its switching tasks by spatially and temporally interchanging the digital data assigned to particular timeslots in different data streams. If the TMS and TSI frames that perform this switching are thought of as processor peripheral devices, then the SPs and DIFs may be thought of as the buffers and device driver for the 1A Processor.

Communication between the 1A Processor and its peripherals (SPs, TMS, etc.) is carried by the Peripheral Unit Bus, which passes through the Processor Peripheral Interface (PPI) and is distributed to the peripherals through the Peripheral Unit Branching Bus (PUBB). Direct communication between the 1A Processor and the external world is effected through the IOP. The Attached Processor Interface (API) handles communication between the AP and the 1A Processor.

Finally, numerous support functions for power supply, conversion, and distribution, switch telemetry and maintenance; and various miscellaneous activities such as ringing and tone generation are required for the 4 ESS Switch to operate and switch traffic intelligibly. These functions are provided by the remaining bays.

2.1.2 Physical

The floor plan of the EMP test 4 ESS Switch appears on Figure 1, and a list of frame-by-frame abbreviations is given in Table 1. Briefly, there are four lineups plus the MCC, the 415 (140V) power plant and the 3B20 computer. The first lineup, containing the CC-1 and CC-0 frames, may be thought of as the processor lineup; the second, the switching-device interface; the third, the switching lineup; and the fourth, the power lineup.

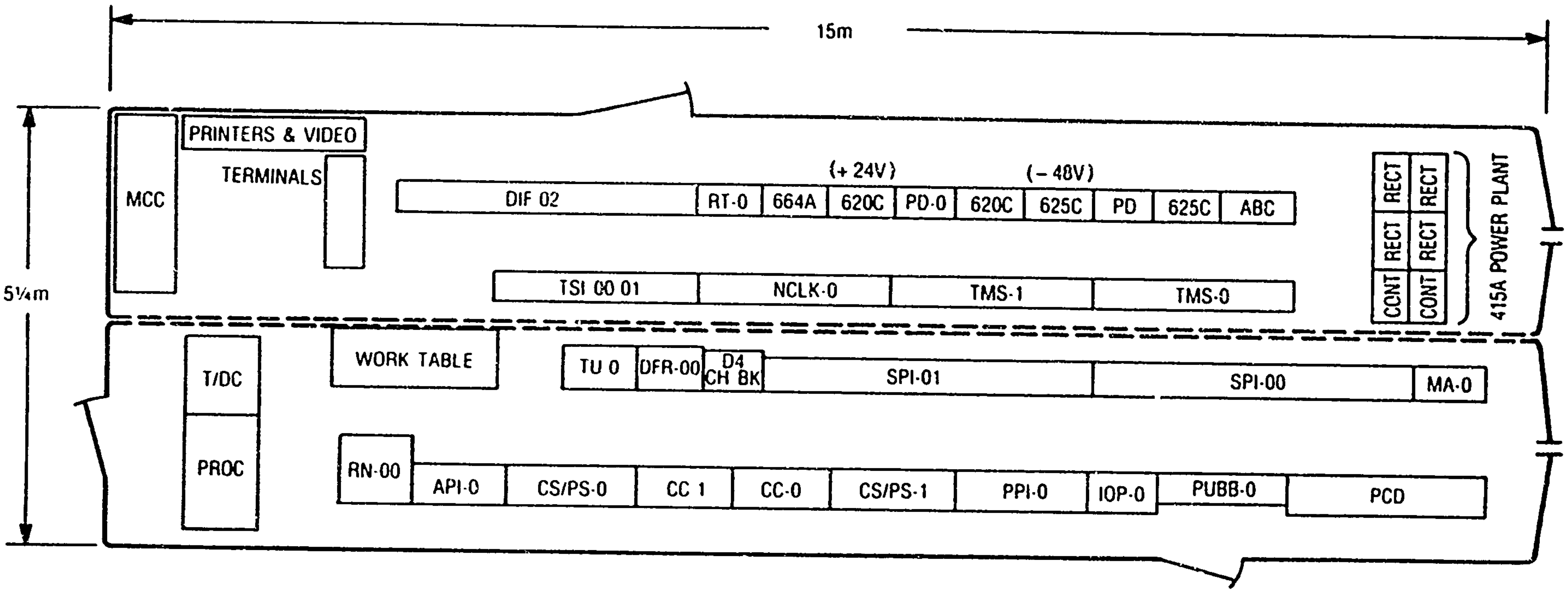


Figure 1. Floor plan of the 4 ESS Switch test trailers.

TABLE 1. Frame-By-Frame Abbreviations.

ABBREVIATION	DEFINITION
ABC	Area Bus Center
API	Attached Processor Interface
CC	Central Control
CONT	Power Control and Distribution
CS/PS	Call Store/Program Store
D4	D4 Channel Bank
DFR	Digital Facility Rack
DIF	Digital Interface Frame
IOP	Input/Output Processor
MA	Miscellaneous A
NCLK	Network Clock
PCD	Power Conversion and Distribution
PD	Power Distributing
PPI	Processor Peripheral Interface
PROC	3B20 Computer
PUBB	Peripheral Unit Branching Bus
RECT	Rectifier
RN	CNI Ring Node Cabinet
RT	Ringing and Tone
SP1	Signal Processor
T/DC	Tape/Disc Cabinet
TMS	Time-Multiplexed Switch
TSI	Timeslot Interchange
TU	Tape Unit
620C	+24V power converter
625C	−48V power converter
664A	−24V power converter

2.2 DIRECT DRIVE DEVICES

All of the current injection was performed with test equipment designed or modified for testing the 4 ESS Switch. The power was supplied in all of the current-injection schemes by a separate high-voltage pulsed-power supply except for the Waveform Emulation Module, (WEM)-jector, which had an integral power supply.

2.2.1 Pulsed Power Supplies

Pulsed power for each injection technique came from one of two Marx generators manufactured for AT&T Bell Laboratories by Ion Physics, Inc. The high-output Marx was a six-stage unit; the lower output Marx, a two-stage unit.

A Marx generator is a combination energy accumulator and switch. It accumulates energy by converting AC power to high-voltage DC power that charges a bank of capacitors This bank of capacitors is divided into stages, and when the Marx generator is discharged, the stages are switched from parallel to series interconnection, multiplying the output voltage relative to the charging voltage by the number of stages. The switches between the stages are spark gaps, which break down in a cascade action when initiated by a trigger gap.

2.2.2 WEM-Jector

Low-level currents were injected onto individual cables and wires with the WEM-jector. The unit comprised a 600V power supply charging a 1 μF capacitor bank, switched by a Silicon Control Rectifier (SCR) and stepped up in current through a 10 to 1 transformer. This provided a low-impedance high-current driver for the EG&G Inductive-Current Transformer (ICT) to which it was connected. This method proved suitable for coupling currents of ~ 1 ampere to small cables or several wires.

2.2.3 High-Level Current Injection

High-level direct-drive coupling required the use of the six-stage Marx generator which could discharge approximately 4,000 amperes of current into a #2 15 kVA primary driver cable. Thirty meters of the cable were laid in the cable trough along the entire length of a lineup of bays and looped back to the Marx generator for ground termination. This provided sufficient inductive coupling to drive several hundred amperes of current through a bundle of secondary colinear cables. This technique also evoked some direct arcing from the driver cable.

2.2.4 Low-Level Electromagnetic-Field Illumination

In order to generate a free electromagnetic field whose effects could be localized in the switch, the two-stage Marx generator was used. A special "gun-barrel" type of antenna was designed wherein the cable stub from the Marx generator was discharged through a 5 kΩ terminating resistor. The resistor was housed in a metal cylinder backed with high-mu metal. The point where the cable sheath was split into a pigtail and grounded to the barrel presented a discontinuity in the propagation characteristics of the coaxial transmission line and caused the electromagnetic field to spill out of the barrel. Although a free-space field, resulting coupling was inductive in nature.

2.2.5 Moderate-Level Electromagnetic-Field Illumination

During low-level illumination, occasional arcing from the coaxial center lead to the barrel ground occurred due to the curvature caused by the positioning of the cable stub from the Marx generator. Following such incidents, wide-scale disruption occurred in the switch, even in bays in other lineups. This was because more energy can be dissipated in the electromagnetic field by an arc than by passing current through a resistor.

To exploit this phenomenon, a spark gap was designed and constructed through which the Marx generator could be discharged. At full charge, the six-stage Marx generator could easily initiate a breakdown across a 4-centimeter gap, the nominal gap spacing used. Because of the length of the radiating element, only high frequencies on the order of 100 MHz were radiated efficiently. This, in fact, represents the most efficient frequency range for coupling to smaller circuit leads. An electric field strength of several thousand volts per meter could be realized in this manner. For an EMP waveform to produce a signal of equal magnitude in the same frequency band would require a peak amplitude of perhaps tens of thousands of volts per meter.

2.3 DATA ACQUISITION

The physical and operational responses of the switch were recorded by our data acquisition system. Physical data (field levels, currents, voltages, etc.) were transmitted fiber-optically using a Nanofast OP-300A fiber-optic link to a LeCroy 6880B digitizer. These data were then recorded and displayed on an AT&T PC6300.

Call-processing information was taken by 5 Ameritec AM1 Plus-D T1 Bulk Call Generators, as directed by one of the AT&T 3B-600 computers. Some T1 bulk call generators were instructed to make calls as quickly as possible (transient calls), periodically reporting the number of calls attempted, and the number of calls successfully completed. Telephone numbers were changed at random after the units reported the information. Other T1 bulk call generators were required to maintain calls indefinitely through the switch, and report when voice path connectivity was lost or later regained. Call-processing statistics were entered into files which could be displayed almost immediately.

3. METHODOLOGY AND RESULTS

3.1 TESTING PROTOCOL

Testing commenced by subjecting individual bays of the switch to the field generated by the small field simulator, with fields of about 500 V/m. (See Figure 2.) The field was localized primarily to one bay but nearby bays received some stress. In this way, a broad picture of the gross susceptibilities of the switch was gained. More precise localization was accomplished using the WEM-jector which induced transients on individual wires connected to the bays with currents from 0.1 amperes to 10's of amperes.

After selectively stimulating separate bays, disruption associated with widespread stimulation of the switch by the high-voltage spark gap was investigated. Fields generated by the spark gap were on the order of 3 kV/m at the backplanes of the switch. (See Figure 3.)

Finally, large cable currents on long cables in the switch were generated by inducing currents on cables in the cable trays. Currents on groups of 24 cables were about 1000 amperes (Figure 4); while on single cables the currents were about 40 amperes (Figure 5).

The different types of transient generators created stresses with different frequency spectra, which covered the range of frequencies expected from an EMP. The low-level field simulator and the spark gap generated signals containing primarily frequencies from 60 MHz to 140 MHz. Lower frequencies were induced by the large current inductor on long bus cables, where the lower frequencies are most important.

3.2 RESULTS

Information was collected in four areas. In the first area, a determination was made of the various sensitivities of the switch to the pulse. This included the functioning of power supplies and whether individual frames could continue to operate. In the second area, an attempt was made to determine the effectiveness of various efforts to improve the response of individual parts of the switch. In the third area, the recovery actions of the switch were monitored and an investigation was made of some alternative strategies for switch reconstitution. Also investigated was the effect of multiple pulses on switch recovery. In the fourth area, the call-processing capability of the switch was determined in terms of making new calls or maintaining existing calls following a pulse.

3.2.1 Sensitivity

Following more than 95 percent of the test pulses, at least one part of the switch was affected to some degree. The most innocuous response of the switch was to register an interrupt from

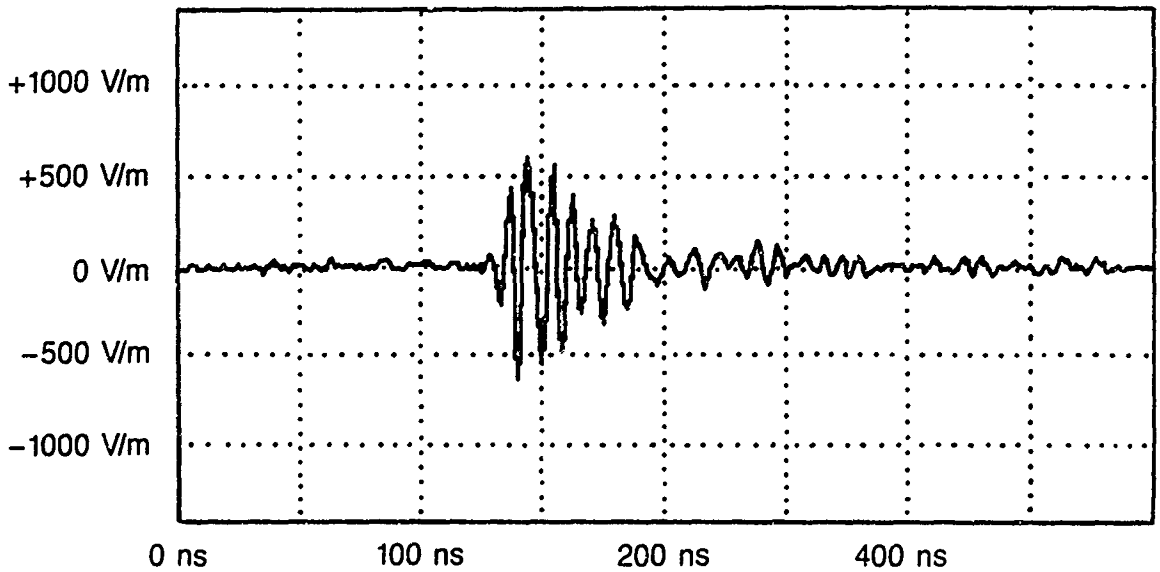


Figure 2. Electric field from small field generator, about 0.5m from source.

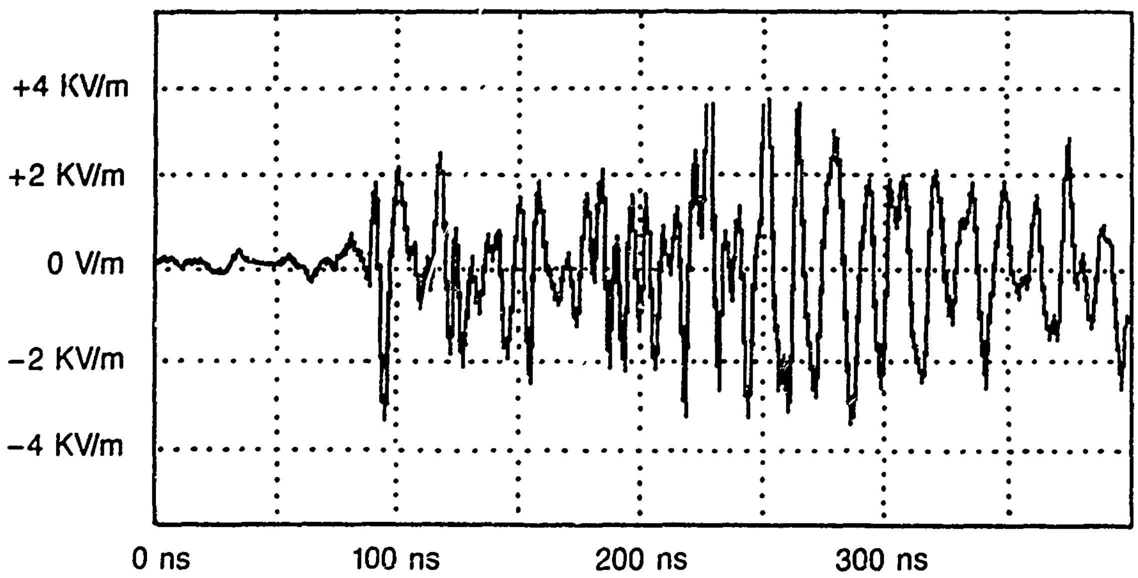


Figure 3. Field from spark gap measured at backplane of PPI.

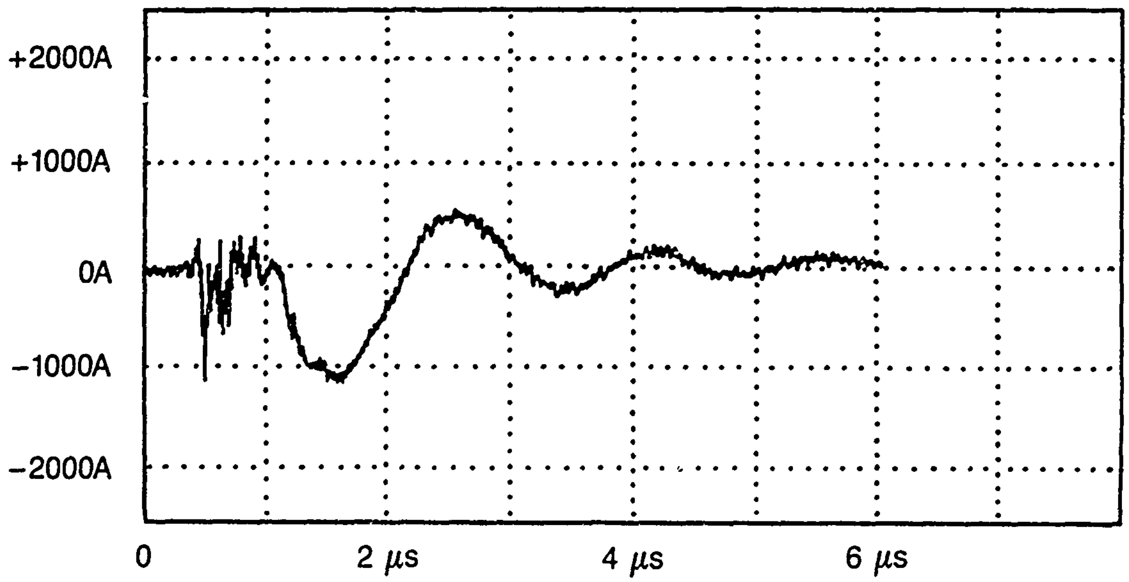


Figure 4. Current on bundle of 24 cables between PPI and MCC.

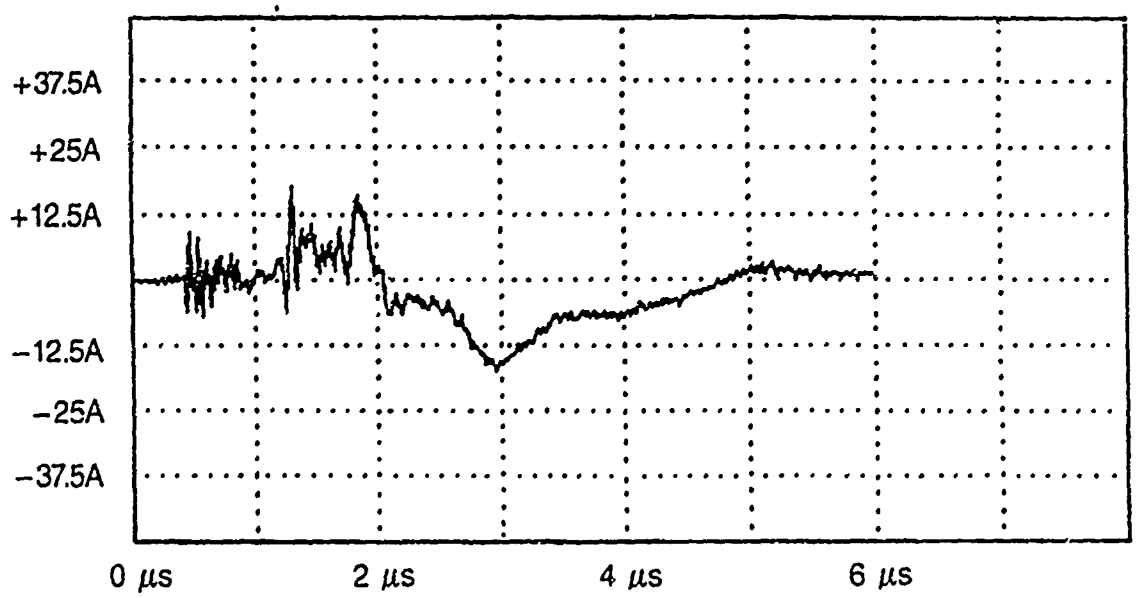


Figure 5. Current on 1 cable between PPI and MCC.

one or more pieces of peripheral equipment. These interrupts were accompanied by a message on the 1A Processor console, and the equipment was not removed from service. The most easily observed effect of a pulse on the switch was the loss of a power bus caused by power converter shutdown. It was often necessary to keep power on the equipment before more subtle responses of the switch could be observed. Other problems, specific to the bays affected, were also noted. These will be described in the following paragraphs. Most of the responses described were found using the low-level field generator. Those uncovered by different stimuli will be explicitly stated.

3.2.1.1 Interrupts

When pulsing in the vicinity of most of the bays (with a radiated field of about 500 V/m) an interrupt was usually generated. These interrupts (from the DIF, TSI, SP, or TMS) were generally accompanied by a printout on the maintenance console and occasionally by the 1A Processor running diagnostics on the affected pieces of equipment. The precise source of these interrupts was not determined.

In the vicinity of the 1A Processor itself, generally one bus on each of the Call Stores and Program Stores would go out of service, as well as one or more of the Call Stores or Program Stores themselves. No hardware damage was observed in these bays. In more than 50 percent of the pulses, the active CC became the standby and the switch continued call processing. Frequently, the switch would request to take a "phase", wherein all or part of the operating program would be reloaded from the 3B20 computer to the 1A Processor. Phase levels go from 1 (a minor update) to 4 (a complete copy of the operating program is sent, as well as zeroing of the processor's core).

3.2.1.2 Power

Power converters in almost every frame showed susceptibility to direct coupling from the field to the circuit board controlling the power converter, which generally resulted in the converters powering down. Susceptibility to shutdown was noticed in the following converters or controllers:

Power Converter Shutdowns

Power Converter or Controller	Location or Function
620C	140V to +24V Bulk Converter
625C	140V to –48V Bulk Converter
FC554	Voltage Monitor for 3V on TMS and TSI
J87389-E	–3V on API, PPI
J87389-F	+3V on API, CC, PPI
J87389-J	+5V on PPI
J87389-M	+3V on IPUB, NCLK, SP, TMS, TSI
J87389-S	+5V on SP
140A (TG4)	DIF
140E	DIF
140L1	DIF
142C (FC76)	NCSU

The sensitivities arose from coupling transients into the High-Voltage Shutdown (HVSD) circuitry, either onto voltage sense leads or onto leads carrying a shutdown signal. No hardware damage was found after these shutdowns.

Hardware damage was observed in two power supplies in the SPs (J-87389-E and J-89389-S) during the high-level cable current injections over the SP lineup. The damage, which was probably caused by transients on the 24V input bus, was sustained on a reference voltage chip in each of the power supplies. This damage occurred on only one of the bays of the SPs; the SPs were still functional. This result may have been an artifact of the testing arrangement, due to arcing from the primary driver cable, and not characteristic of the types of transients expected from an EMP.

3.2.1.3 Oscillators

The 39B Oscillators were susceptible to radiated transients on the 5V power leads, frequency control input leads and shields, and the digitally controlled input cables. These oscillators provide a reference frequency to the DIF, TSI, and TMS to ensure that they all act in synchronization with one another. When pulsed, the reference frequency generated by an oscillator would usually change to either its low or high extreme value. The DIF, TSI, and TMS would then begin to generate interrupts. Some of these interrupts probably were caused by timing mismatches between them, a consequence of the wrong reference frequency being put out by the oscillators.

3.2.1.4 PUB

The two-way communication between the 1A Processor and the peripheral equipment, via the PUB, could be disrupted by a pulse. When the 1A Processor expected one of its peripherals to respond with a particular signal, and that signal became garbled by the pulse, the 1A Processor occasionally removed the device from service. Thus, the 1A Processor sometimes responded as though more equipment were malfunctioning than was actually the case.

3.2.1.5 PPI/MCC

During the spark-gap tests and the large current driving tests, the cables connecting the PPI with the MCC coupled transients that resulted in the MCC being taken out of service. This occurrence stopped the MCC, the main operator/machine interface, from accurately displaying the status of the machine. Also disabled were some of the diagnostic functions available on the MCC. However, the operator could still request the machine to take a phase, i.e., a software reinitialization.

Hardware damage was noted when these transients burned out transistors driving some of the lights on the MCC panel. About 10 of these transistors were so destroyed. This damage did not prevent the proper operation of the push buttons that the lights illuminated.

3.2.1.6 CCS 7 Node

When the large-current cable driver was over the 1A Processor lineup, the CCS 7 interface card and nodes sustained hardware damage preventing them from functioning. This damage was caused by transients directly induced on the lines connecting the CCS 7 interface node on the CNI ring and the 56-kb/s modems. CCS 7 messages were immediately stopped, which was service disrupting. This problem could have been an artifact of the test arrangement, i.e., arc discharges from the driver cable, and may not be caused by EMP-like transients.

3.2.2 Reduction of Sensitivity

While trying to determine the precise nature of the susceptibilities mentioned, ways to decrease the sensitivity of various parts of the switch were investigated.

3.2.2.1 Interrupts

Interrupts are software responses to hardware problems. Since the switch's operation is only temporarily affected by a single given interrupt, no actions were proposed to reduce the switch's cognizance of interrupts.

3.2.2.2 Power

Power converters were generally desensitized by filtering the sensitive components of the HVSD with capacitors. The affected circuitry is shown in the following schematics. Figure 6 shows the modifications for the FC554 circuit pack: Figure 7 shows the modifications of the circuit packs in the 620C and 625C power plants; Figure 8 shows the modification needed for the 140L1 power converter; Figure 9 shows the modifications required for the 87389-E, -F, -J, -M, and -S power converters. Modifications to the power converter and controller circuits are given in the following table.

Modifications of Power Converters and Controllers

Circuit Pack	Modification
620C (+24V)	0.07 μF from IC14D, pin 14 (HVSD shutdown signal) to ground
FC554 (TSI and TMS 3V Monitor)	0.01 μF from IC4, pin 5 (shutdown signal) to ground 0.01 μF from IC4, pin 10 (shutdown signal) to ground 0.001 μF from Q19 base to collector (shutdown signal) 0.001 μF from Q23 base to collector (voltage sense signal)
140L1 (3V)	0.01 μF from IC201, pin 1 (shutdown signal) to pin 5
87389-E, -F, -J, -M, -S	100 pF from IC1, pins 17 and 18 (shutdown signal) to ground

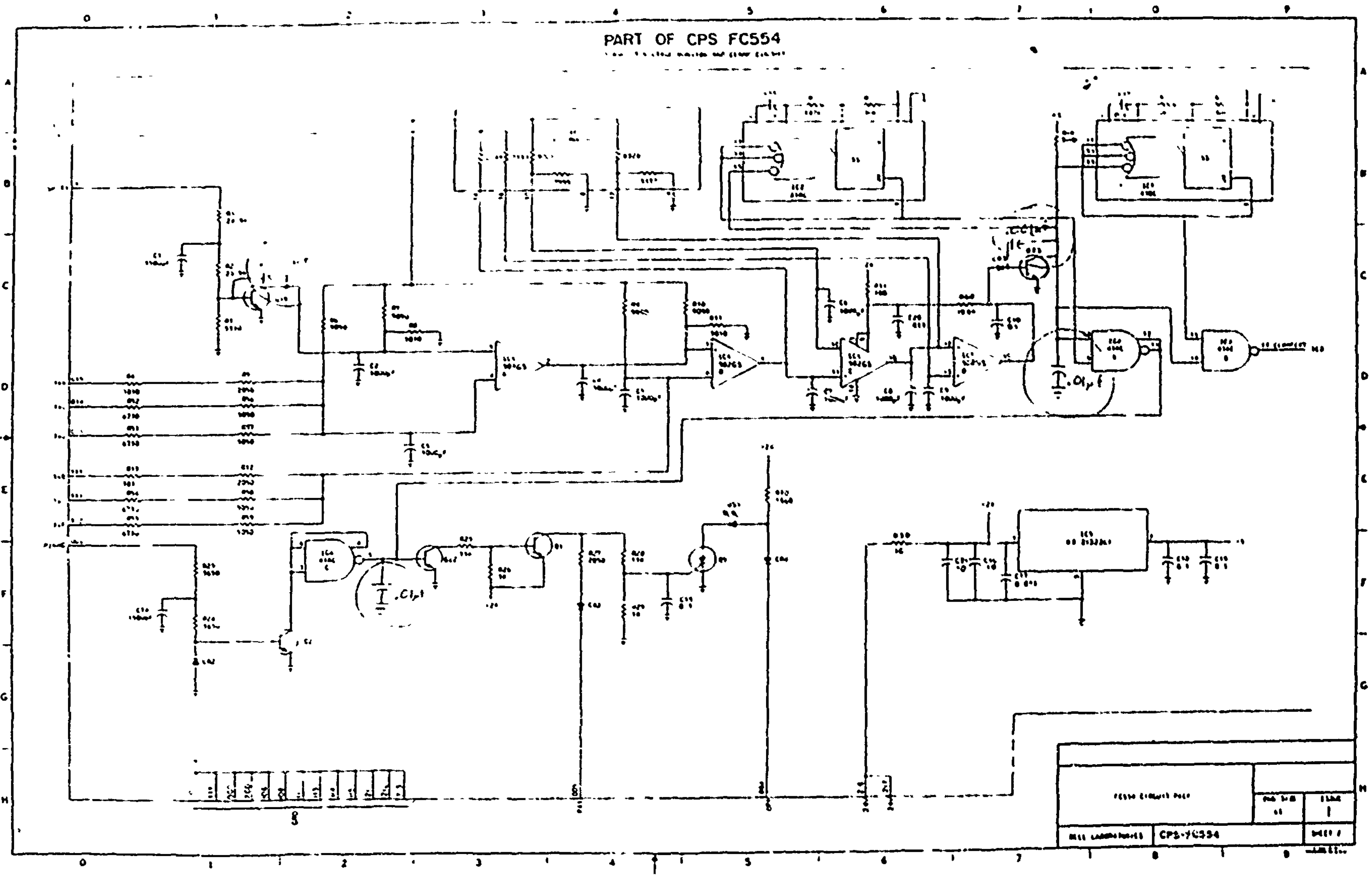
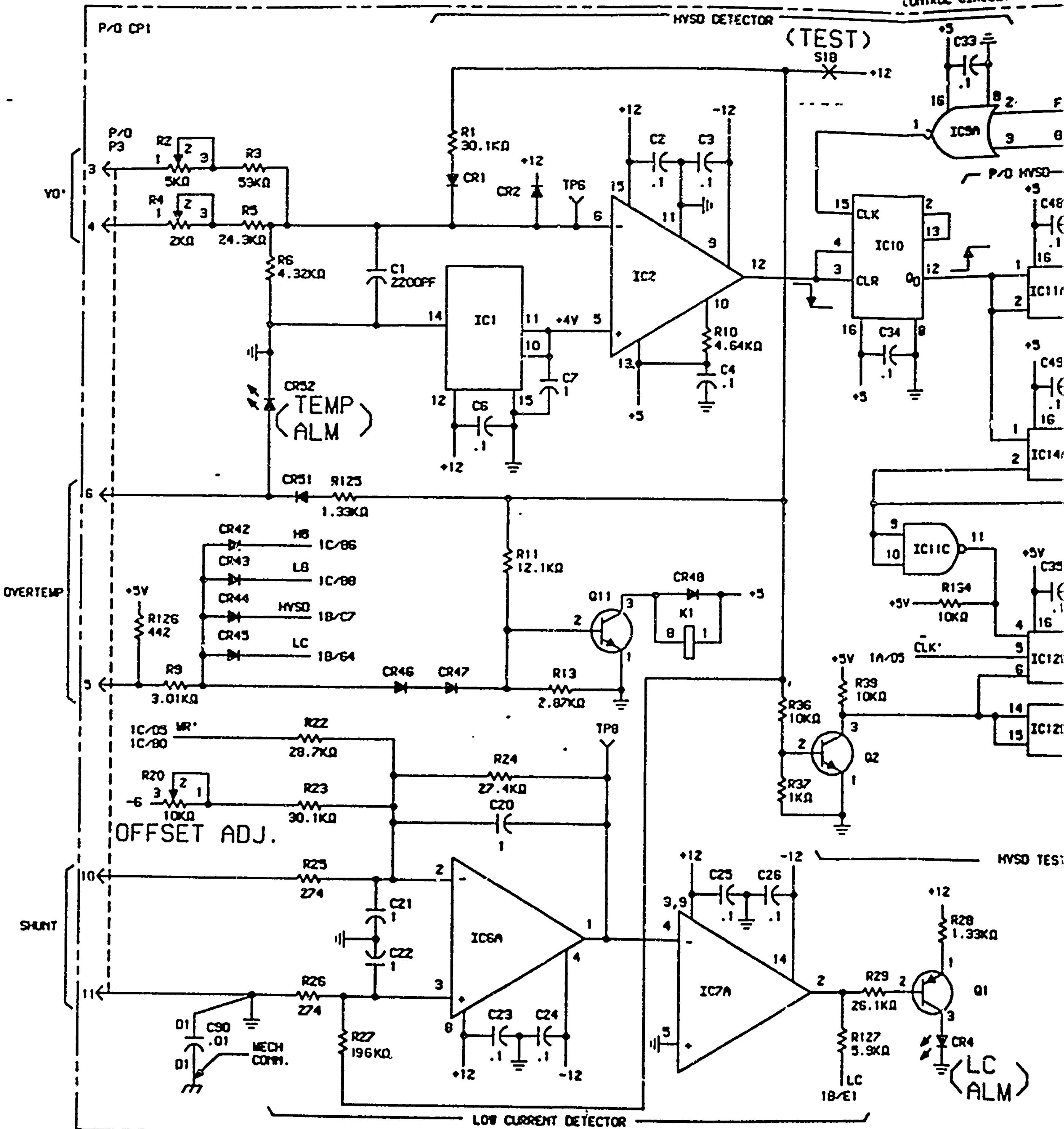


Figure 6. Schematic of 554 circuit pack, with modifications circled.

PART OF CPS1
CONTROL CIRCUIT



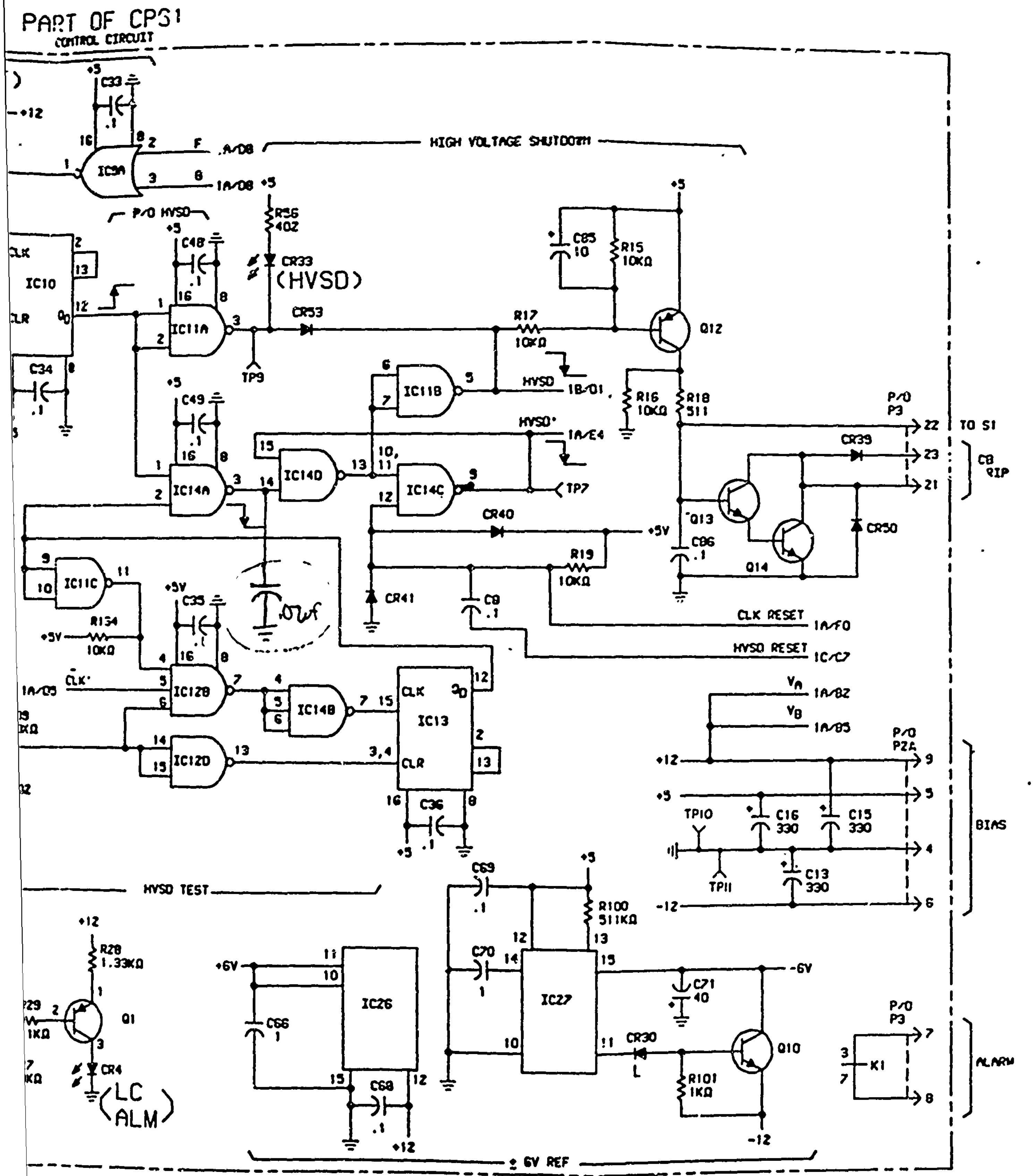
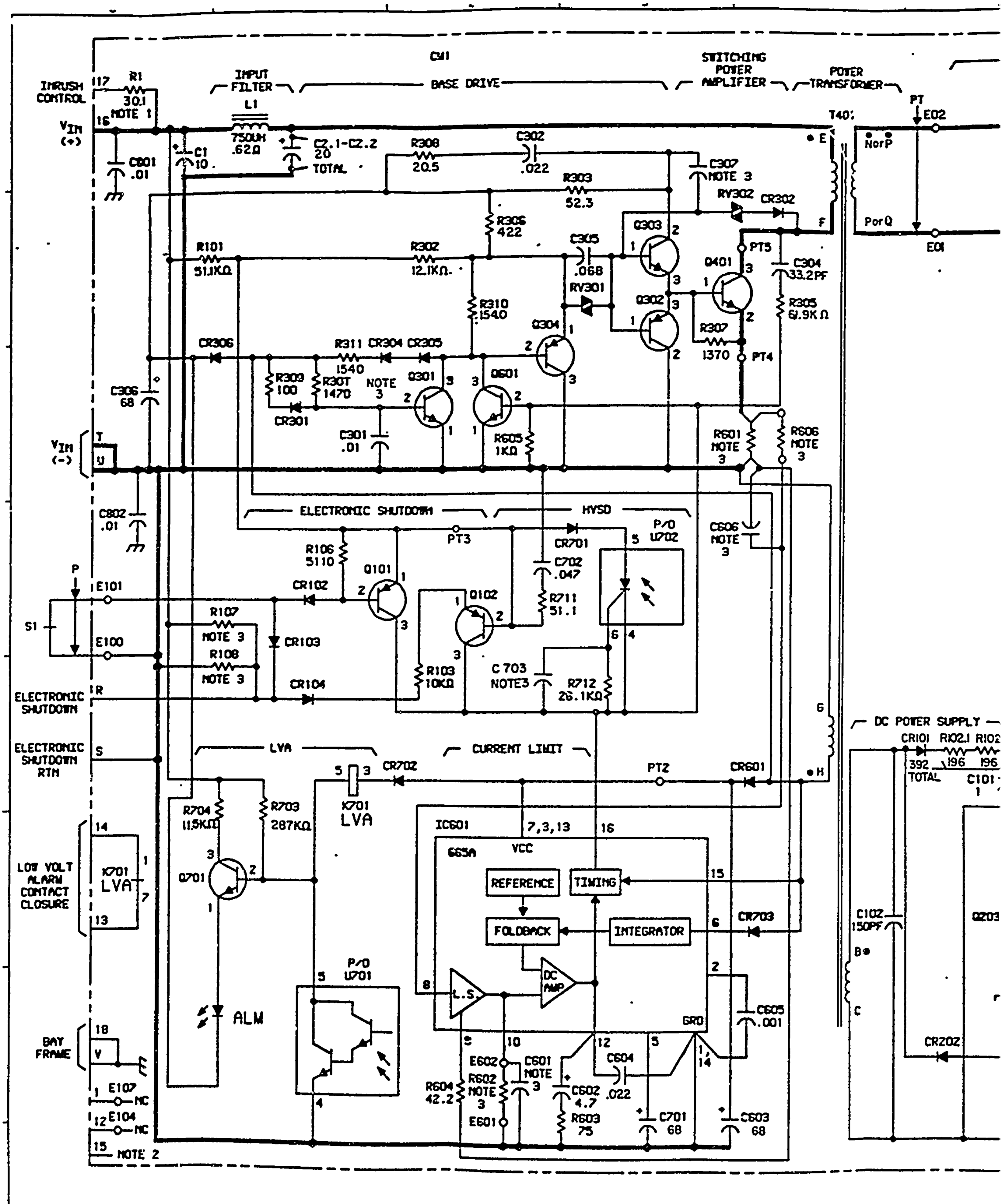


Figure 7. Schematic of circuit pack in 620C and 625C power plants, with modification circled.



NOTES:
1. SHORT FINGERS.
2. INTERNAL CONNECTION. DO NOT CONNECT TO.
3. DESIGNERS CHOICE COMPONENTS.

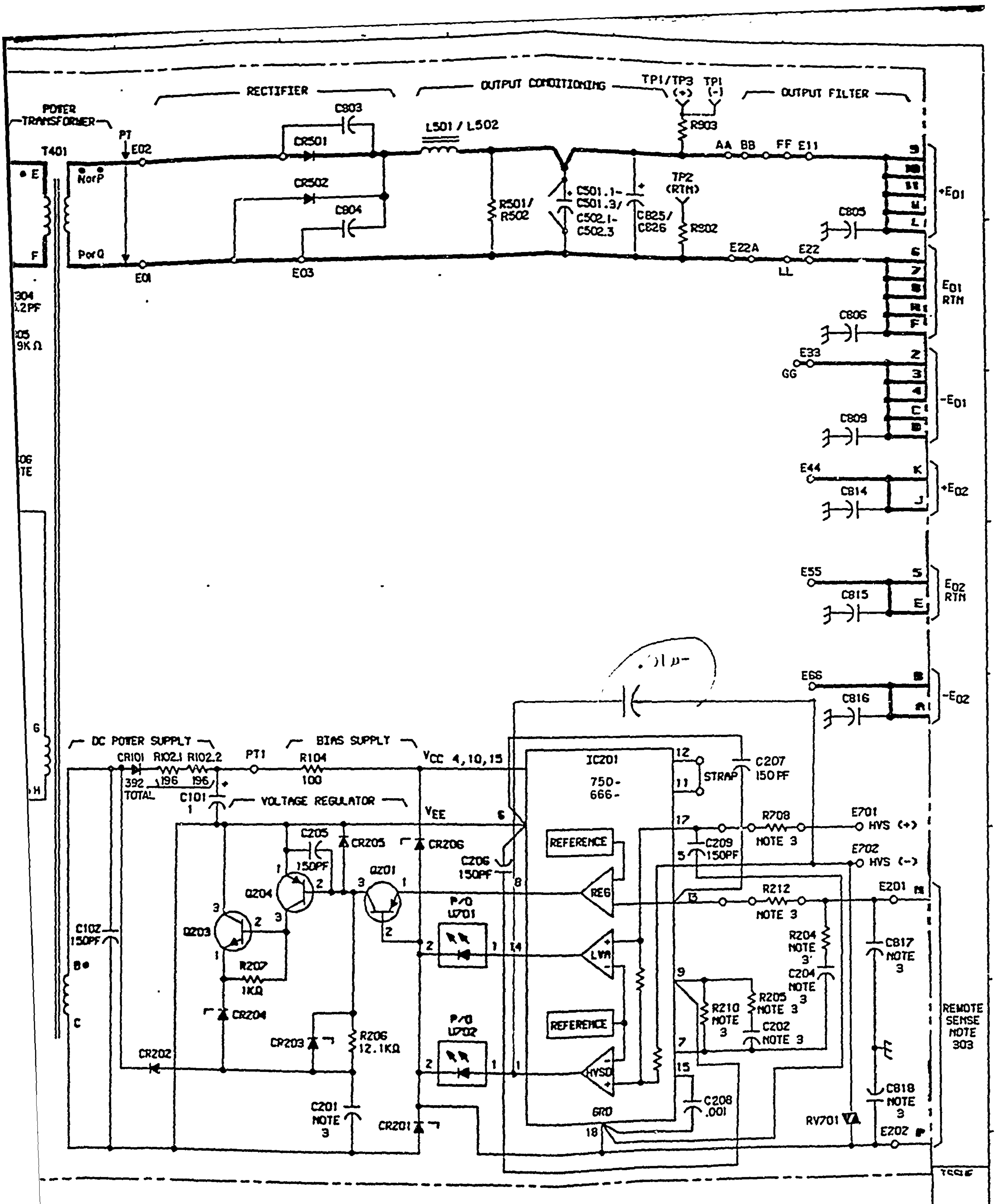
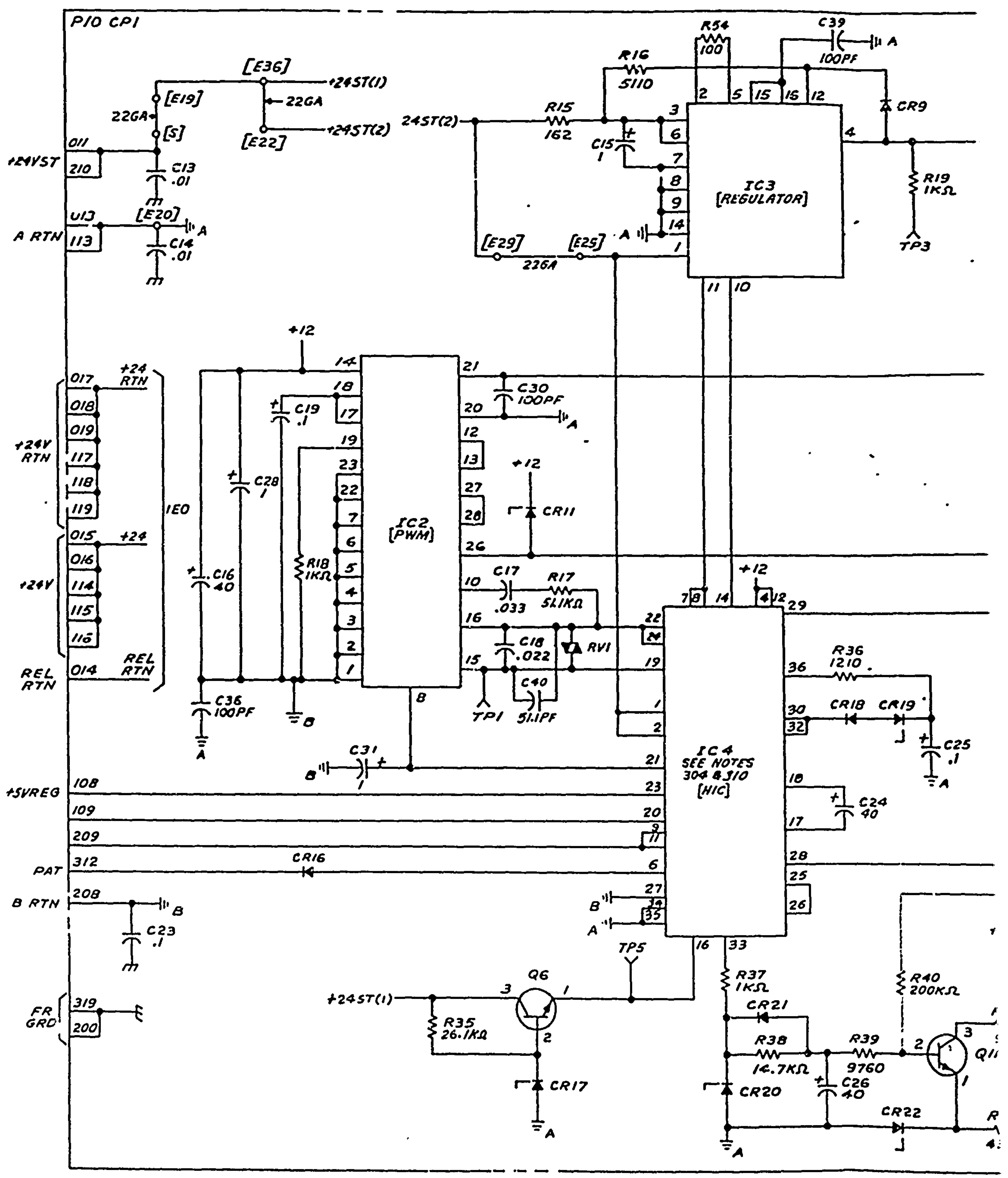


Figure 8. Schematic of 140L1 circuit pack, with modification circled

PART OF F:



P10 CP1
[E36]
+24ST(1)
22GA
+24ST(2)
[E22]
[E19]
[S]
+24VST
A RTN
[E20]
C13 .01
C14 .01
R54 100
C39 100PF
R16 5110
R15 162
24ST(2)
C15 1
IC3 [REGULATOR]
CR9
R19 1KΩ
TP3
[E29]
[E25]
226A
+12
IC2 [PWM]
C30 100PF
C19 .1
C28 1
C16 40
R18 1KΩ
C36 100PF
CR11
C17 .033
R17 51.1KΩ
C18 .022
RV1
C40 51.1PF
TP1
+24 RTN
+24V RTN
+24
+24V
REL RTN
IE0
IC4 SEE NOTES 304 & 310 [HIC]
R36 1210
CR18
CR19
C25 .1
C24 40
C31 1
+5VREG
PAT
CR16
B RTN
C23 .1
FR GRD
TP5
Q6
+24ST(1)
R35 26.1KΩ
CR17
R37 1KΩ
CR21
R38 14.7KΩ
R39 9760
C26 40
CR20
R40 200KΩ
Q11
CR22

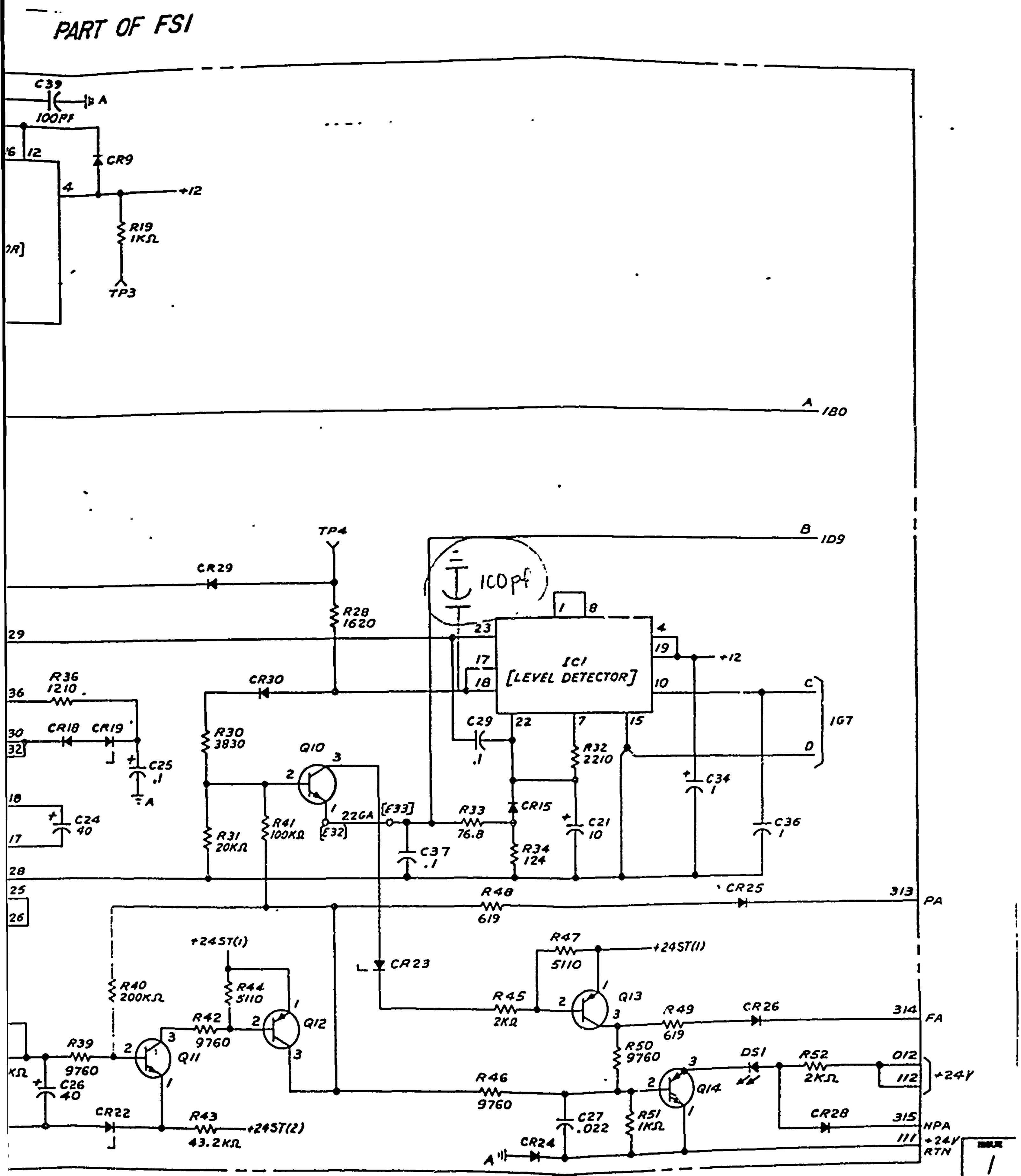


Figure 9. Schematic of circuit pack for 87389-E, -F, -J, -M, -S power converters, with modification circled.

3.2.2.3 PUB

No actions were taken to mitigate the switch's response to garbled information on the PUB because the switch normally recovers automatically. However, should this become necessary, possible solutions include shielding the PUB or allowing the processor software to reiterate a query to which it received an incorrect response.

3.2.2.4 CCS 7

No actions were proposed to reduce the sensitivity of the CCS 7 nodes, since the observed trouble could have been caused by an arc from the driving cable. If this problem recurs during the ALECS testing, filters on the interfaces to the cables connecting the CCS 7 node and the 56 kbps modems should fix it.

3.2.2.5 Oscillators

The inputs to the oscillators were protected by capacitors or shielding to prevent EMP-induced disruptions. The modifications are listed in the following table.

Modifications of Oscillators

Lead	Treatment
5V and RTN	1 μF from each lead to ground
Frequency Control	1 μF from each lead and its shield to ground Input and Shield
Digital Frequency Control Cables	Shield cables in metallic zipper tubing

3.2.2.6 PPI/MCC

To reduce sensitivity of the PPI and MCC, the cables connecting these pieces of equipment were encased in shields consisting of metallic zipper tubing.

3.2.3 Recovery of Switch

The actions taken to bring the switch back to its normal state depended upon the severity of the problems it faced. When low-level interrupts occurred in the peripheral equipment, the processor either ignored the symptoms or placed the suspected malfunctioning equipment out of service and started diagnostics. If the equipment did not suffer extensive upset from the pulse, it was usually returned to service following successful completion of the diagnostics. Otherwise, the affected equipment remained out of service. Generally, the diagnostics took from one to several minutes to run on each piece of equipment.

When there were severe disruptions in the peripheral equipment or problems arose internal to the 1A Processor itself (e.g., the CC, Program Store, or Call Store community), the switch usually took the more severe action of requesting a software reinitialization ("phase"). In requesting a phase, the CCs receive a partial or a complete new copy of the operating program from either the Attached Processor System (APS) or the Tape Unit (TU). In more than half of the pulses that directly stressed the CCs, the active CC was taken out of service and the standby one was brought into service. After some severe pulses of the 1A Processor, the switch also needed to establish a working configuration of a CC, a PS Bus, and an Auxiliary Unit (AU) bus. Typically, the program transfer took 1 to 2 minutes; the time needed by the switch to recover thereafter depended upon the peripheral equipment that was still out of service. Recovery times at this stage ranged from less than 1 minute to about 45 minutes.

Manual intervention was sometimes necessary or desirable in the process of switch recovery and was needed when some aspect of switch configuration prevented automatic restoration. For example, these instances occurred during power converter shutdown which required manual reset or when a circuit pack required reseating to become operational. While the modifications of the power circuitry obviated most of these problems, there were times when power cycling of the equipment was needed to bring the switch back into service. Elements requiring power cycling included the PSs, the MCC, the IOP, and sometimes the API. On two occasions when the switch requested a phase and both APIs were out of service, the 1A Processor continuously cycled through its configurations in an attempt to initiate communication with the APSs. Once one of the APIs was power cycled, however, the 1A Processor immediately chose a configuration and initiated the data transfer.

Manual intervention was also desired when there was more equipment out of service than the 1A Processor could keep track of (due to the finite length of the maintenance queues), or when equipment did not recover until after the diagnostics were initiated. If a peripheral device was in the process of recovering from a pulse, but the 1A Processor had already decided that the equipment was no longer functioning, it required human intervention to return the peripheral device to the list of equipment to diagnose. In these instances, without manual assistance, the processor would begin to process a long line of diagnostics whose conclusion would not result in a working (i.e., call-processing) switch. Having manual guidance in determining the recovery actions or requesting the switch to take a phase can effect a working switch faster than the switch's default actions.

The switch's own recovery activity stopped when one or more additional pulses were administered while the switch was still engaged in taking a phase. When multiple pulses occurred, the transfer of the new program stopped, and the switch did not restart it. The switch then ceased to recover nor did it process calls. Manual intervention, either directly on the MCC or remotely via the E2A telemetry, was required to reinitiate a phase.

3.2.4 Call Processing

The 4 ESS Switch was designed to process calls, and much of its equipment is duplicated so that if any one piece of equipment should fail, call processing should continue uninterrupted. In our tests, the 4 ESS Switch has shown a remarkable robustness in servicing calls even when a significant fraction of its equipment is out of service.

When an interrupt on the switch occurred, call processing was usually interrupted for a few seconds (~ 15) while the 1A Processor determined what actions were required to deal with the interrupt. If no further actions were needed, call processing resumed as normal. However, if the problem was significant enough to get the switch to initiate a phase, a further interruption in call processing would ensue. This interruption lasted for the time needed for the phase (from a few seconds for a phase 1 to about 2 minutes for a phase 3) plus an additional time needed to bring on line peripheral equipment required to process calls. Altogether, call interruptions lasted from 2 to 10 minutes. (See Figure 10.)

Stable calls were affected only by high-level phases or when the equipment servicing the calls was taken out of service (duplex failures in the DIF or TSI). (See Figure 11.) Otherwise, they usually remained connected. One interesting mode observed was when the processor was incapable of processing new calls, and the stable calls were still connected through the switch. The DIF, TSI, and TMS were intelligent enough to continue the stable call connections. These calls stayed up until the processor regained its sanity. When the processor initialized the DIF, TSI and TMS, they then knocked down the stable calls.

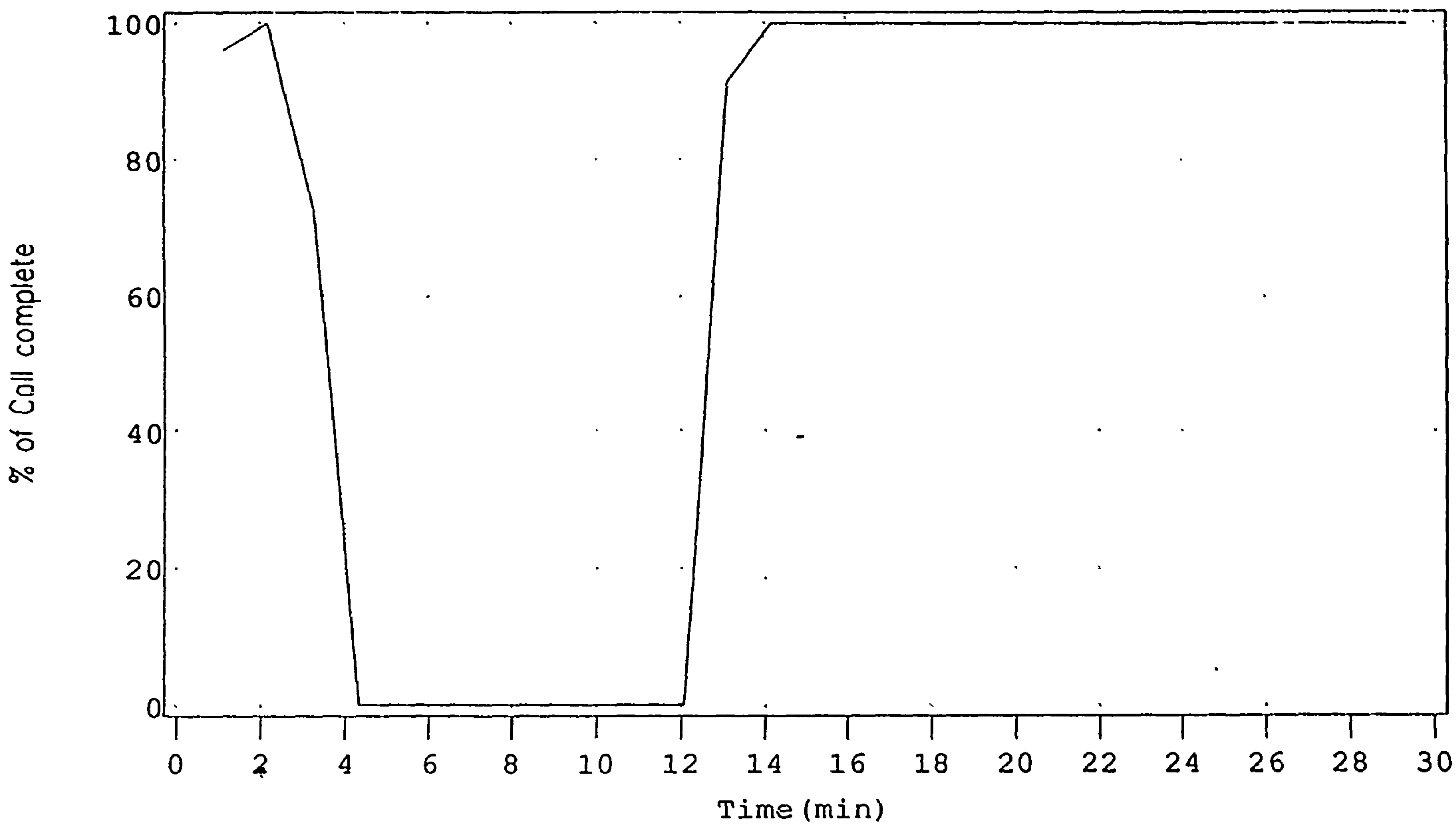


Figure 10. Percentage of transient calls completed before and after pulse.

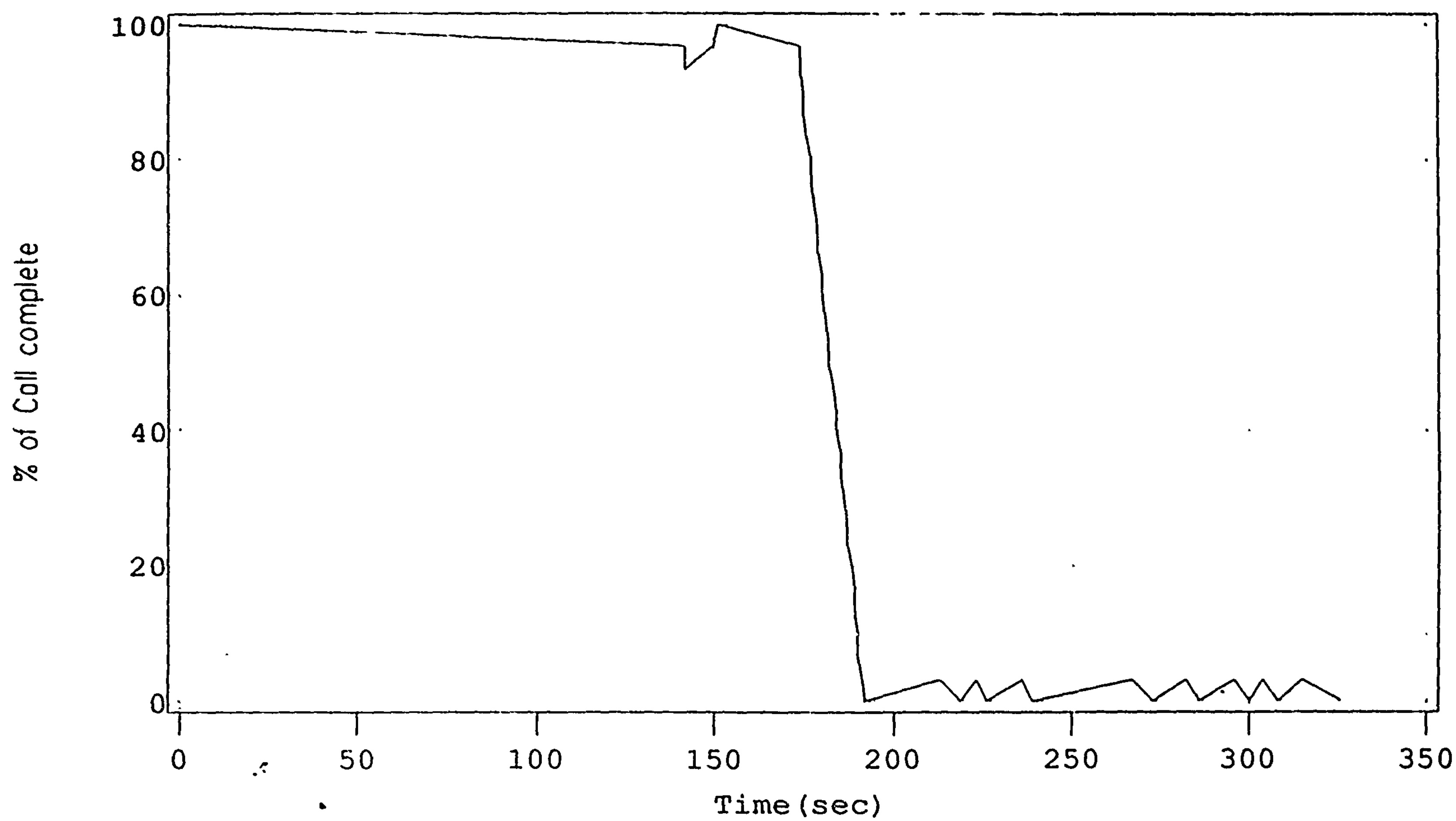


Figure 11. Percentage of stable calls connected before and after pulse.

4. CONCLUSION

AT&T Bell Laboratories has completed a program of direct-drive current injection and radiated-field current coupling on the 4 ESS Switch. The individual test sequences roughly reproduced in the laboratory the variety of electromagnetic stresses that might affect a 4 ESS Switch following a high-altitude nuclear burst. Although little actual hardware damage was observed, a number of potential equipment sensitivities were identified and remedial circuit modifications designed and implemented. With a few simple modifications, most notably to the power converters, the 4 ESS Switch demonstrated considerable robustness in servicing calls following current-injection stress. Despite the number of service-degrading conditions that were generated in the switch, no situations arose in which operator intervention or the fault recovery software proved unable to restore the switch to full service.

Continuity of the assessment team has been maintained from test bed installation through laboratory testing; that same team will accompany the system through the ALECS test phase. The experience thus will optimize the chances for a positive outcome of the 4 ESS Switch EMP Assessment Program.

APPENDIX A

GLOSSARY

TERM	DEFINITION
AFWL	Air Force Weapons Laboratory
ALECS	AFWL/Los Alamos Scientific Laboratory EMP Cablibration and Simulation
AP	Attached Processor
API	Attached Processor Interface
APS	Attached Processor System
ASN	AT&T Switched Network
AU	Auxiliary Unit
CC	Central Control
CCS 7	Common Channel Signaling System 7
CNI	Common Network Interface
DIF	Digital Interface Frame
EMP	Electromagnetic Pulse
HVSD	High-Voltage Shutdown
ICT	Inductive-Current Transformer
IOP	Input/Output Processor
MCC	Master Control Console
NCS	National Communications System
PPI	Processor Peripheral Interface
PSN	Public Switched Network
PUBB	Peripheral Unit Branching Bus
SCR	Silicon Control Rectifier
SP	Signal Processor
TMS	Time-Multiplexed Switch
TSI	Timeslot Interchange
TU	Tape Unit
WEM	Waveform Emulation Module